BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Unmanned Lunar Logistic Systems
Case 340

DATE: September 9, 1968

FROM: R. Sehgal

ABSTRACT

The Titan IIID/Centaur and the Saturn IB/Centaur are two potential candidates for unmanned lunar logistic systems. The Titan IIID/Centaur can deliver approximately 3,300 lbs of useful payload to the lunar surface as compared to approximately 5,100 lbs for Saturn IB/Centaur.

Economical considerations alone make a strong case for the application of Titan IIID/Centaur. However, other factors such as possible availability and higher payload capability are attractive features in favor of Saturn IB/Centaur.

The option of developing a common landing stage/spacecraft for the two logistic systems would provide a flexibility of intermediate size payloads with the final vehicle choice dependent upon cost, availability, and mission objectives.

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MEMORANDUM FOR FILE

INTRODUCTION

To increase the scientific return from lunar surface missions after the first few Apollo landings, one of the most important needs is the delivery of payloads such as scientific equipment, mobility aids and expendables which cannot be carried to the lunar surface in a manned single-launch system. This introduces a need for an unmanned payload delivery system for lunar surface rendezvous and exploration. The Santa Cruz meeting and subsequent lunar exploration plans made strong recommendations that Saturn V dual launch capabilities be developed. The unmanned system would consist of the LM where all the ascent features are to be eliminated and replaced by logistic payload items and their support systems with a payload capability of approximately 10,000 lbs. The strategy consisted of landing the unmanned vehicle first with a CEP of approximately 100m and the manned vehicle to rendezvous with this as close as possible.

This dual launch approach and rendezvous strategy which seemed highly desirable from the lunar exploration standpoint raised some serious questions as to the use of Saturn V vehicles in a dual launch mode. The questions essentially related to the cost and availability of Saturn V vehicles along with the effective use of large payloads in the early phases of the lunar exploration program.

Subsequent studies which considered missions from the early-to-mid 1970's concluded that meaningful exploration programs could be conducted with a shorter staytime (3-7 days) and logistic requirements far less than the Saturn V payload capabilities.

This led to a detailed investigation of the available intermediate class of launch vehicles as potential candidates for unmanned lunar payload delivery systems. It was readily concluded that the two most promising launch systems in this category were the Titan III family of launch vehicles and Saturn IB. The Atlas SLV-3X seemed to be a poor third choice due to its relatively poor performance and capabilities.

For upper stage application, the potential candidates seem to be Agena D, Centaur, and Service Module. Other available configurations are not compatible with the objectives and the development of a new upper stage is not warranted under the existing guidelines and application requirements.

Based on this preliminary information, MSFC is in the process of issuing an RFP for a study contract to determine the performance, capabilities, and integration requirements for the potential candidate launch vehicles and conceptual spacecraft configurations along with definition of launch facilities, support equipment, and overall costs. Some of the pertinent guidelines for this study are: application in the 1972-75 time period, cost considerations, maximum utilization of available systems, facilities, equipment, spacecraft hardware, and current state-of-the-art technology.

Concurrent with this study, a working group on intermediate spacecraft and launch vehicles has been established at NASA Headquarters with somewhat parallel but broader objectives of evaluating overall lunar payload delivery systems and establishing design guidelines and specifications for the landing stage/spacecraft configuration.

The objectives of this memorandum are to assess the relative merits and associated costs of candidate launch vehicles and upper stage systems for application in the 1972-1975 time period.

LAUNCH VEHICLES

As previously stated, the two launch vehicles which are compatible with the objectives of this study are the Titan III and the Saturn IB. The capabilities and adaptation of the Titan III family of launch vehicles have been the subject of a previous memorandum[1] and thus its discussion is limited to areas pertinent to this study. There are two members of this family which have a potential application; namely, Titan IIID and Titan IIIF. The Titan IIID is the same vehicle as the Titan IIIC but without the transtage and minor modifications in software. The Titan IIIF is similar to the Titan IIIM (currently being developed by the Air Force) but will utilize an upper stage. The difference between the Titan IIIF and Titan IIID is that the F vehicle has stretched tanks in the first and second stages and utilizes two

7-segment 120 inch solid rocket motors in stage 0. Other vehicles such as the Titan IIIG are outside the scope of this study as this vehicle utilizes 156 inch solid rocket motors in stage 0, which requires a new development program and thus strictly represents a growth potential in the Titan III family of launch vehicles.

The configuration, payload capabilities, and status of Saturn IB have been documented comprehensively[2] and thus will not be repeated in this memorandum.

As previously mentioned, for upper stage application the potential candidates are: (1) the Agena D, (2) the Centaur, and (3) the Service Module. Again, these are developed systems and their descriptions and potentials are well documented[3,4,5] and thus will be omitted in this memorandum. Other proposed systems such as Improved Agena are not compatible with the objectives as this would represent a new development program to uprate the present Agena engine.

For the various combinations of launch vehicles and upper stages, Table I below provides approximate spacecraft weight that can be injected in translunar injection. In all cases it is assumed that the upper stage will be separated from the spacecraft after translunar injection. The obvious unattractive combinations are not shown in this table.

TABLE I

INJECTED LANDING STAGE/SPACECRAFT WEIGHT SUMMARY

Launch Vehicle	Upper Stage	Translunar Injection by	Injected Spacecraft Weight Lbs
Titan IIID	Agena D	Agena D	7,400
Titan IIID	Centaur	Centaur	13,000
Titan IIIF	Agena D	Agena D	10,500
Titan IIIF	Centaur	Centaur	18,000
Saturn IB	Agena D	Agena D	8,500
Saturn IB	SM	SM	8,800
Saturn IB	Centaur	Centaur	18,300

The Titan IIID and Saturn IB are considered fully developed operational launch vehicles with known performance, capabilities, availability, reliability, and total launch costs.

The Titan IIIF (Air Force designation IIIM) is being developed under the Air Force program and probably will become operational in the 1971-1972 time period. The performance of this vehicle is comparable with that of Saturn IB and maximum launch loads for the two vehicles are approximately equal (4 g's). Thus Titan IIIF may be an excellent substitute for Saturn IB in case the Saturn IB program is phased out or is not cost effective. However, one drawback is that new facilities will be required for East Coast launch.

Since the Titan IIIF vehicle is not operational and cannot be considered in the same context as the Titan IIID or Saturn IB, it will not be considered further in this study except to keep in mind its potential capabilities for application in the 1972-1975 time period.

The upper stage candidates mentioned previously are considered fully developed operational systems, other than few modifications required for their adaptation to the proposed launch vehicles.

As indicated in Table I, both the Service Module and the Agena D have significantly poor performance as compared to the Centaur stage and thus their application will severely limit the payload capability that can be delivered to the lunar surface. The potential application of the Service Module is only with the Saturn IB vehicle as it would represent an integration problem (bulbous upper stage) with the Titan III vehicles. The selling point for Agena D is that the nonrecurring Titan IIID/Agena integration costs have been borne by the Air Force and if the Lunar Exploration Program can live with small payloads such as 1,000 - 1,200 lbs, then this system may be desirable. However, comparatively large spacecraft development costs with a very limited use of such a vehicle does not justify its application.

The NASA working group on intermediate launch vehicles and spacecraft has established a design goal of approximately 12,000 lbs injected weight to translunar injection with a useful payload delivery capability of approximately 3,500 lbs to the lunar surface. This goal, along with the arguments advanced above eliminates the Service Module and the Agena D from further consideration as candidates for upper stage application.

This elimination process leads to the Centaur system as the most promising upper stage for the two candidate launch vehicles. The two combinations are referred to as Titan IIID/Centaur and Saturn IB/Centaur. The integration of the 120 inch Centaur stage with either the 120 inch Titan IIID or the 260 inch Saturn IB is not expected to pose any serious problem either in terms of long lead time or in terms of large development costs.

For both configurations, the separation of the cryogenic Centaur stage after translunar injection is desirable from the standpoint of maximum payload delivery capability. This establishes one of the design requirements for the landing stage/spacecraft that it should have its own propulsion system capability for midcourse maneuver (approximately 200 fps) as well as lunar orbit and land or direct descent from lunar transfer trajectory (ΔV requirements are approximately the same for both cases $\approx$ 9,000 fps). Assuming storable propellants with a specific impulse of approximately 305 seconds, Table II indicates the approximate useful payload for the two configurations.

LAUNCH SYSTEM COSTS

Launch vehicle cost estimates are probably the most controversial as they vary widely from one data source to another depending upon the assumptions made. This is particularly true of the Saturn class vehicles.

In an attempt to arrive at the cost estimates for the two candidate launch vehicle systems, the following sources of cost data were used.

1. NASA (OSSA, MSFC) cost data

2. U. S. Air Force cost data

3. Manufacturer/Contractor cost data

Cost estimates are shown in terms of recurring and nonrecurring costs without detailed breakdown. This is intentionally done in order to avoid discussion of small differences among individual items at this time. An explanation is provided for any major differences.

TITAN IIID/CENTAUR

Once all the cost estimates are analyzed and basic assumptions deciphered, one finds an amazing agreement as to the recurring and nonrecurring cost estimates for this configuration.

TABLE II

PAYLOAD DELIVERY CAPABILITY

Vehicle Configuration	Approximate Injected Weight Lbs	Approximate Propellant Mass Lbs (Vac. Isp≈305 sec)	Approximate Inert Weight Lbs	Approximate Useful Landed Payload Lbs
Titan IIID/Centaur	13,000	7,800	1,900	3,300
Saturn IB/Centaur	18,300	11,000	2,200	5,100

The recurring cost estimates[6,7] for this vehicle from the various stated sources are placed between 21-23 million dollars. These estimates include all the costs for the Titan IIID vehicle and mission support; the Centaur basic vehicle, its mission support and software, adapter and integration costs plus costs for launch services.

The NASA-OSSA[8] recurring cost estimates for this vehicle are placed at 17.4 million dollars. However, these estimates exclude the plant operations costs for Centaur of approximately 20-25 million dollars per year which are assumed to be borne by the Atlas/Centaur program. If these costs are shared by the Titan IIID/Centaur system, the recurring costs will fall between 21-23 million dollars.

The nonrecurring cost estimates for this vehicle from the various sources[6,7,8] are placed between 40-45 million dollars. The general breakdown includes 20-25 million dollars for Titan/Centaur integration costs, approximately 10 million for additional ground support equipment and roughly 10 million dollars for modifications and additions to complex 40 or 41 at the Eastern Test Range.

However, these nonrecurring cost estimates do not include any test launch of the now integrated system. In the author's opinion one such test will be absolutely necessary before the launch system can be considered fully qualified. This will add at least 21-23 million dollars to the nonrecurring costs. Thus the total nonrecurring costs for the Titan IIID/Centaur launch system are placed between 60-70 million dollars.

SATURN IB/CENTAUR

The cost estimates for this launch system are the most difficult to obtain and are considered more controversial than the Saturn V vehicle estimates. At the present there are two detailed studies being conducted; one by Chrysler Corporation under a NASA contract and the other by NASA Headquarters (Rosen Committee) to arrive at some realistic cost estimates for the Saturn IB/Centaur launch system. Until the results of these studies are published, one has to rely on available documented estimates. Thus for the purposes of this memorandum the cost estimates are based on data obtained from NASA/OSSA and NASA/MSFC.

Recurring Costs

As it is well known, the cost data available for all Saturn class vehicles show significant variations with launch rates. The recurring cost estimates for the Saturn IB/Centaur launch system are based on two assumptions: (1) an annual use rate of 4 Saturn IB's and 4 Saturn V's and (2) an annual use rate of 2 Saturn IB's and 2 Saturn V's.

For the 4 x 4 program the recurring costs[8] of Saturn IB/Centaur are placed at 66.4 million dollars for a single launch system. These costs include hardware costs, stage integration, launch, and other support costs.

For the 2 x 2 program the recurring costs[8] are estimated to be 90.1 million dollars for a single launch. Again these costs include the hardware, stage integration, launch, and support costs.

Nonrecurring Costs

The nonrecurring costs for Saturn IB/Centaur are estimated to be the same as those for Titan IIID/Centaur (40-45 million) if they are only based on stage integration, ground support equipment and facilities and no test shots are included. However, there is an additional cost for the shroud adapter. Two types have been considered by MSFC: (1) Spacecraft launch vehicle adapter and (2) new 260 inch shroud adapter. A general breakdown of nonrecurring costs[9] for the two cases are shown below:

	154" SLA	260" SHROUD
Shroud	3.4 M	16.6 M
Saturn IB/Centaur Integration	20-25 M	20-25 M
GSE	10.0 M	10.0 M
Facilities	10.0 M	10.0 M
	43.4-48.4 M	56.6-61.6 M

As pointed out for the previous case, at least one test shot will be absolutely necessary to qualify the launch system and this will add at least 66 to 90 million dollars to the nonrecurring costs.

Assuming the use of 154 inch SLA, which is considered a fully developed item, the nonrecurring costs based on the referenced sources for the Saturn IB/Centaur are estimated to be 115-140 million dollars.

LAUNCH SYSTEMS COMPARISON

Economical considerations coupled with basic vehicle availability based on the Air Force production program and demonstrated reliability of the Titan III family of launch vehicles make a very strong case for the use of Titan IIID/ Centaur as the potential candidate for the unmanned lunar logistics system. However this should not overshadow some of the equally significant factors which make an attractive case for the use of Saturn IB/Centaur system as discussed below.

First of all, as indicated in Table II, the Saturn IB/ Centaur system can deliver approximately 2,000 lbs of additional payload to the lunar surface as compared to the Titan IIID/Centaur system. It is quite possible that for 1972-1975 application the Lunar Exploration Program may require payloads in excess of Titan IIID/Centaur capability. Secondly, there are the practical considerations such as the possible availability of Saturn IB vehicles not used in the anticipated NASA programs, thus making them readily available and economically attractive for the Lunar Exploration Program.

An evaluation of the basic design parameters for the two vehicle configurations leads to the possibility of designing a common landing stage/spacecraft for the two proposed configurations. This would eliminate the necessity of selecting one vehicle over the other at this time in order to proceed with the design and development of the landing stage/spacecraft for the unmanned payload delivery system. This premise is based on factors such as the nearly identical maximum launch loads for both vehicles of approximately 4 g's along with flexibility of payload delivery capability and potential application beyond the 1972-1975 time period. The main drawback to such a proposition is that the landing stage/spacecraft will have to be designed for the largest payload delivery capability (Saturn IB/Centaur) and this will impose a small payload penalty in conjunction with Titan IIID/Centaur due to heavier structure.

CONCLUSIONS

The results of the study indicate that Titan IIID/Centaur and Saturn IB/Centaur are the two potential candidates for unmanned lunar logistic systems. The Titan IIID/Centaur can deliver approximately 3,300 lbs of useful payload to the lunar surface as compared to approximately 5,100 lbs for the Saturn IB/Centaur.

Economical considerations alone make a strong case for the application of Titan IIID/Centaur. However, other factors such as possible availability and higher payload capability are attractive features in favor of Saturn IB/Centaur. The option of developing a common landing stage/spacecraft for the two logistic systems would provide a flexibility of intermediate size payloads with the final vehicle choice dependent upon cost, availability, and mission objectives.

R. Sehgal

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Attachment
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Subject: Unmanned Lunar Logistic Systems   From: R. Sehgal

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